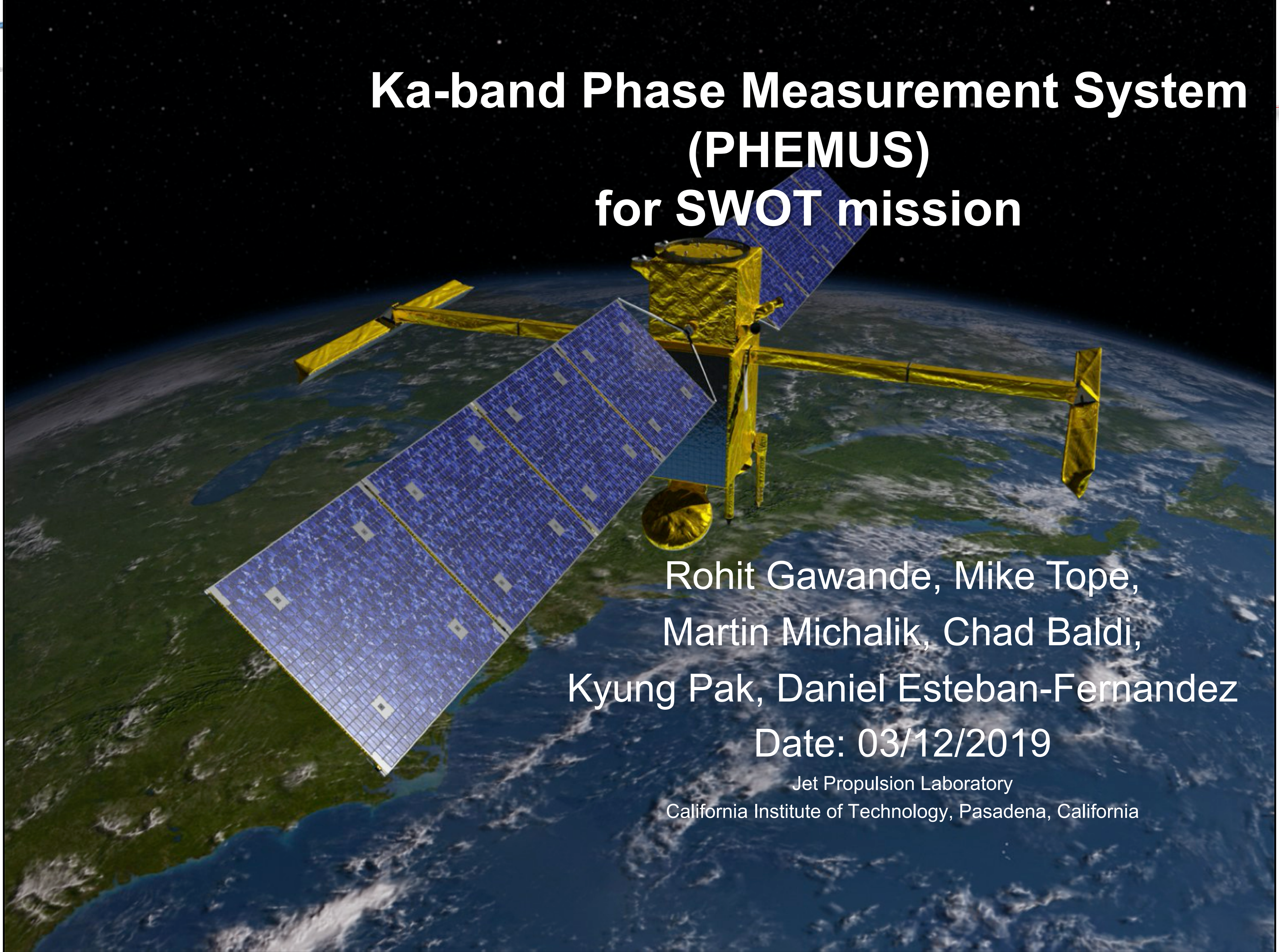

Ka-band Phase Measurement System (PHEMUS) for SWOT mission

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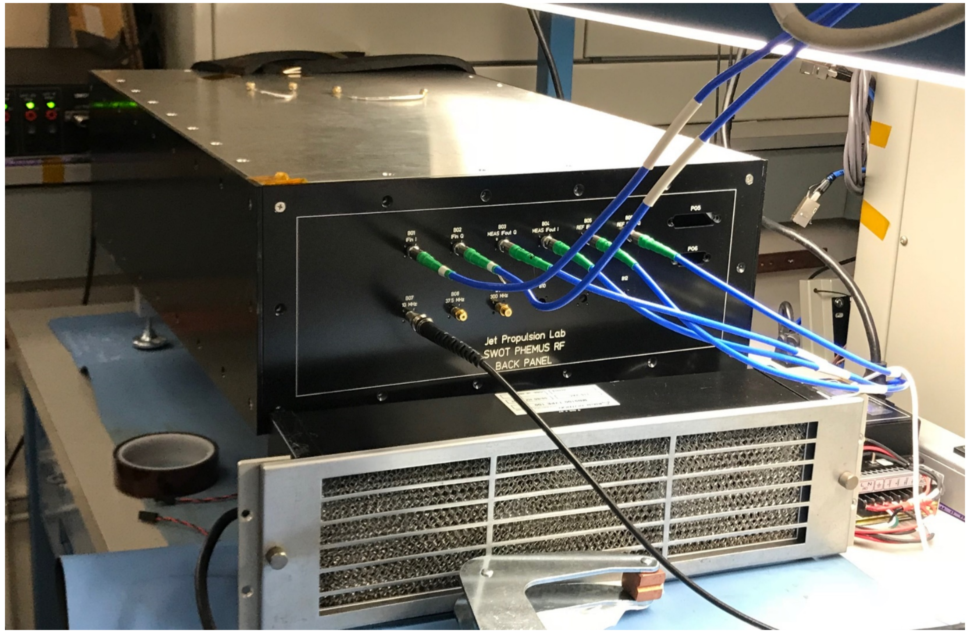
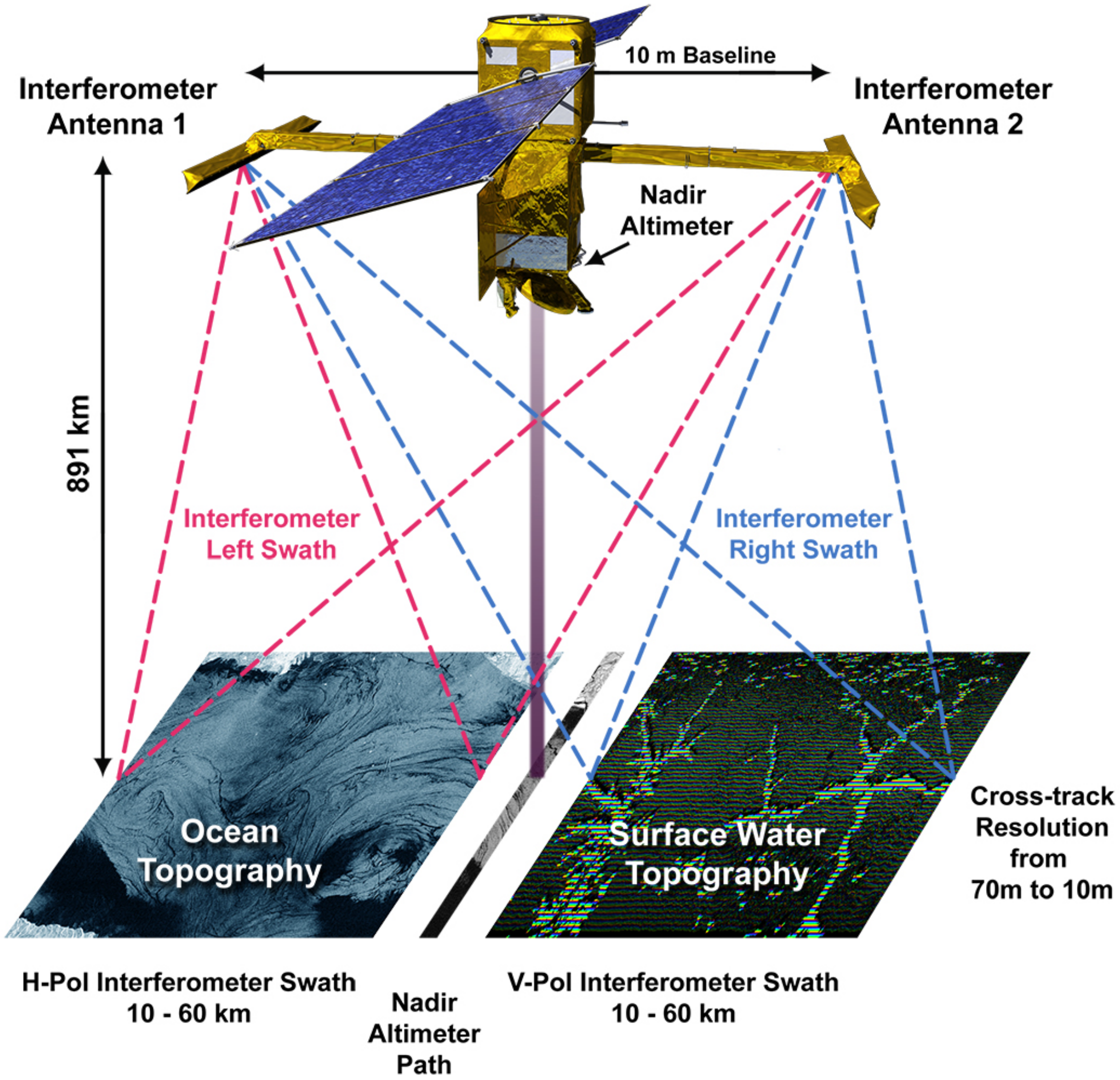
Contents

- SWOT Mission overview
- KaRIn instrument overview
- Interferometric measurement concept
- Sources of errors and sub allocation to GSE
- Need for PHEMUS
- PHEMUS working principle and block diagram
- PHEMUS baseline results
- Summary



SWOT Mission

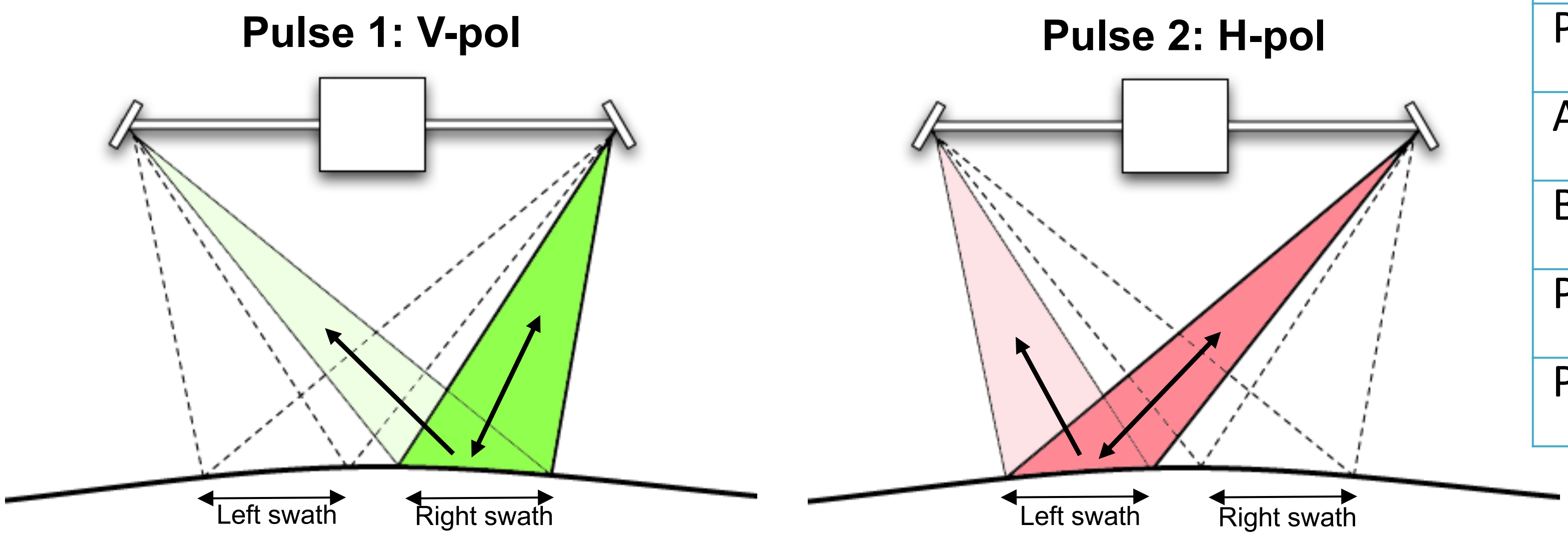
- NASA's first global survey of Earth's surface water
- Supports two communities: Oceanographers and hydrologists by measuring the elevation of the global oceans, as well as terrestrial water bodies.
  - Oceanography: Characterize the ocean mesoscale and sub-mesoscale circulation at spatial resolutions of 15 km and greater.
  - Hydrology: To provide a global inventory of all terrestrial water bodies whose surface area exceeds 250m^2 (lakes, reservoirs, wetlands) and rivers whose width exceeds 100 m (rivers).
  - To measure the global storage change in fresh water bodies at sub-monthly, seasonal, and annual time scales.
  - To estimate the global change in river discharge at sub-monthly, seasonal, and annual time scales.
- SWOT is being jointly developed by NASA and Centre National D'Etudes Spatiales (CNES) with contributions from the Canadian Space Agency (CSA) and United Kingdom Space Agency.
- Societal benefits:
  - predicting climate change,
  - coastal zone management,
  - flood prediction, and water resources management.



Ka-band radar interferometer (KaRIn)

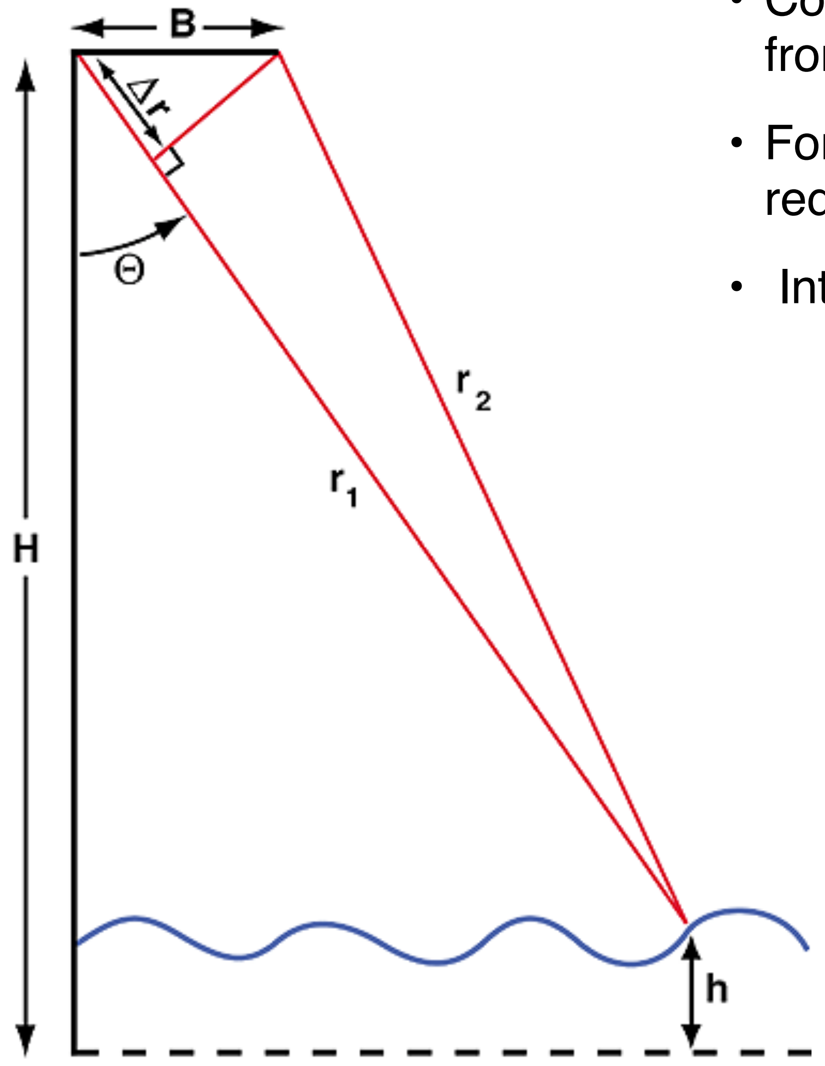
KaRIn is a synthetic aperture ("imaging") radar interferometer operating at Ka-band (35.75 GHz center frequency). The key system parameters are shown in Table.

- The antenna subsystem is formed by two 5x0.25 m deployable antennas on opposite ends of a 10 m deployable boom (which forms the interferometric baseline).
- KaRIn will provide continuous mapping operating in single transmit antenna mode.



Parameter	Value
Center frequency	35.75 GHz
TX Bandwidth	200 MHz
TX Pulse length	5.7 us
Pulse Repetition Frequency (average)	2 x 4420 Hz
Peak Transmit Power (EOL)	1500 W
Physical Baseline Length	10 m
Antenna size	5 m x 0.25 m
Boresight Look Angle	+/- 2.65 deg
Polarization, Right Swath	VV
Polarization, Left Swath	HH

Interferometric Measurement Concept



- Conventional altimetry measures a single range and assumes the return is from the nadir point
- For swath coverage, additional information about the incidence angle is required to geolocate
- Interferometry is triangulation
  - Baseline B forms base (mechanically stable, 10m for KaRIn)
  - The difference between two sides (Δr) is obtained from the phase difference (Φ) between the two radar channels (λ is the wavelength). The phase difference (Φ) enables us to estimate very precisely the view angle (Θ). (Φ) is unwrapped phase derived from auxiliary data.
  - Range r_1, is determined by the system timing accuracy.
  - Platform height H is obtained from nadir altimeter.

$$\Delta r = r_2 - r_1 = B\sin\Theta, \Delta r = \frac{\lambda}{2\pi}\Phi$$

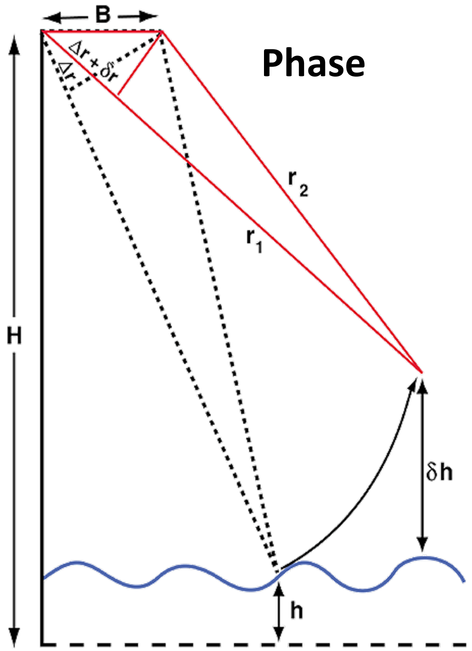
$$\Theta = \sin^{-1}\left(\frac{\lambda\Phi}{2\pi B}\right)$$

$$\mathrm{h} = \mathrm{H} - r_1 \cos\Theta$$

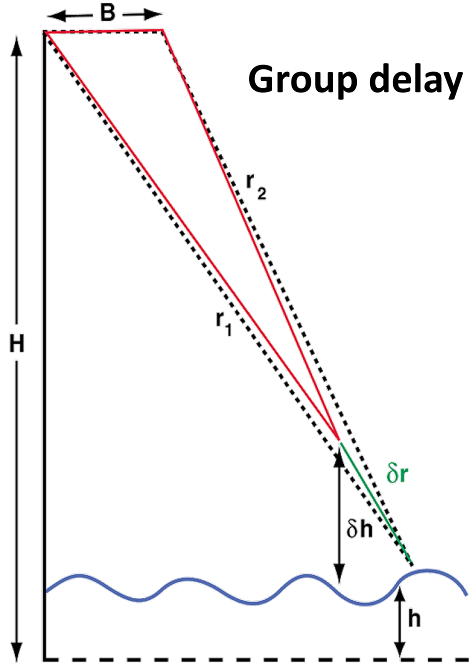
Primary sources of systematic errors

$$\delta h_{phase} \approx \frac{C}{kB}\left(1+\frac{H}{R_E}\right)\delta\phi$$

$$\delta h_{gd} \approx \frac{c}{2}\cos(\theta)\,\delta t$$



0.1 deg phase = ~1 cm height error at center of swath

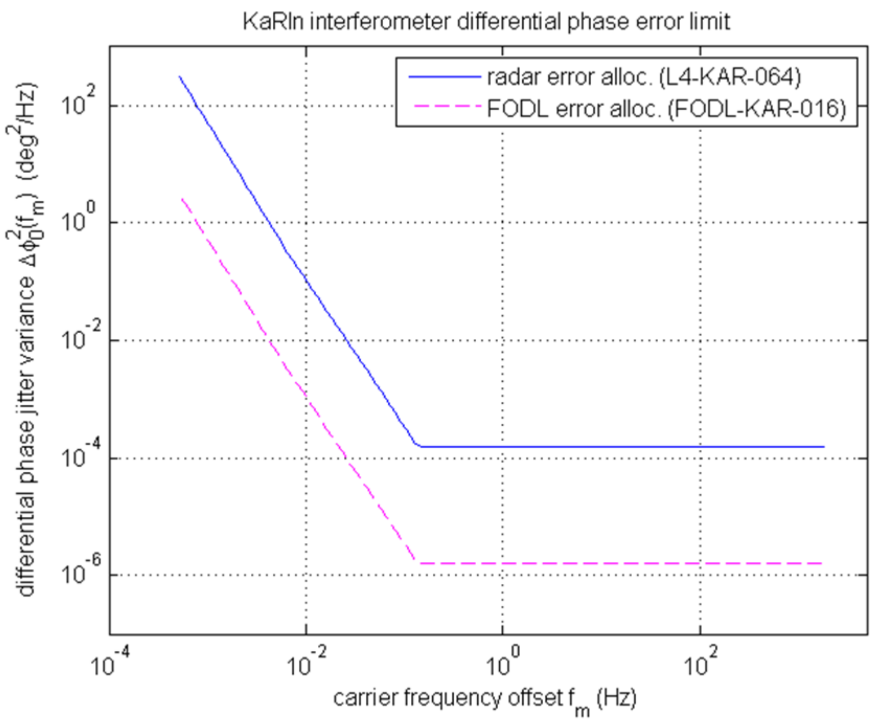


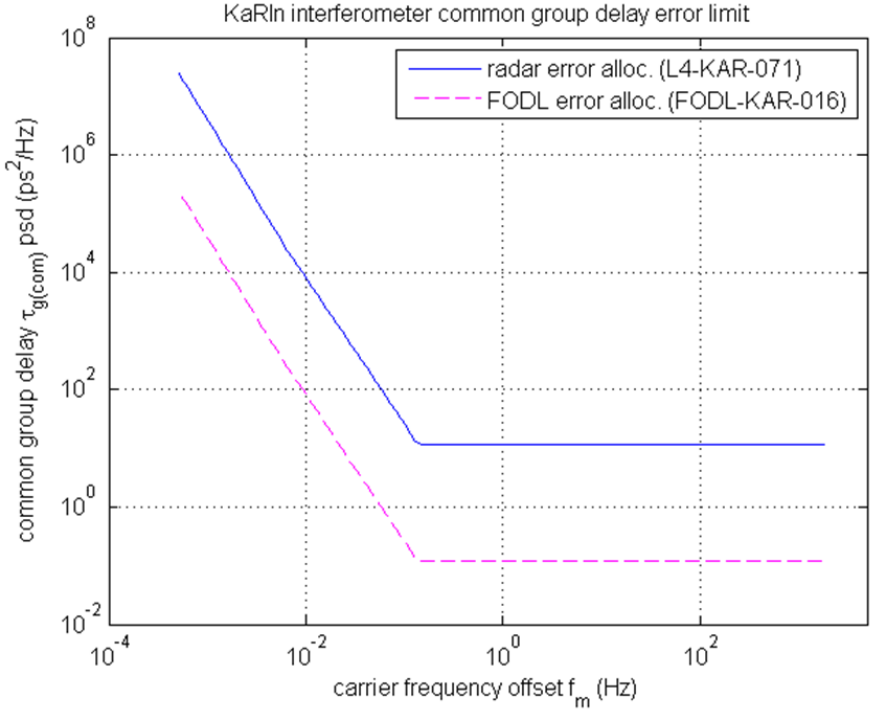
100 ps = ~1.5 cm height error at center of swath

- The primary sources of systematic errors are due to drifts in phase and group delay.
- To achieve centimeter-level accuracy, stringent requirements are imposed on main radar performance.
- The L4 instrument level requirements are:
  - Interferometer differential phase error: **0.58^0 rms**
  - Interferometer common group delay error: **100ps rms**
  - These requirements target the drifts in instrument electronics as a function of time, temperature, vibrations etc.

Key performance requirements
Phase error and group delay error envelopes

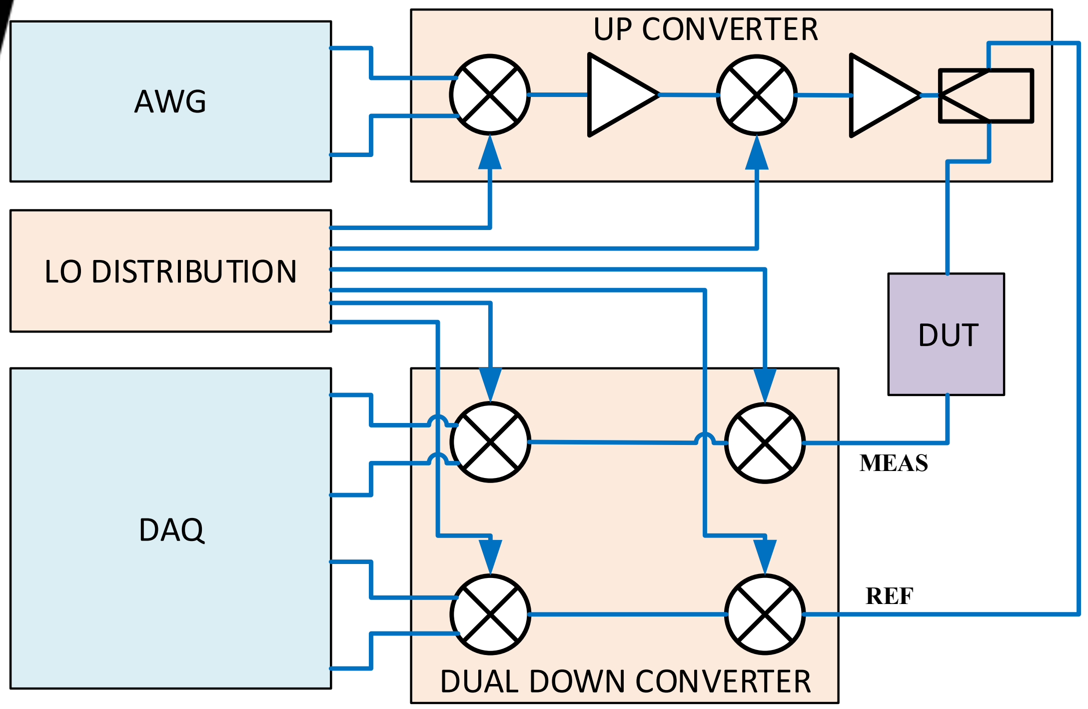
Error psd envelopes defined from 520 μHz to 2.0 kHz.





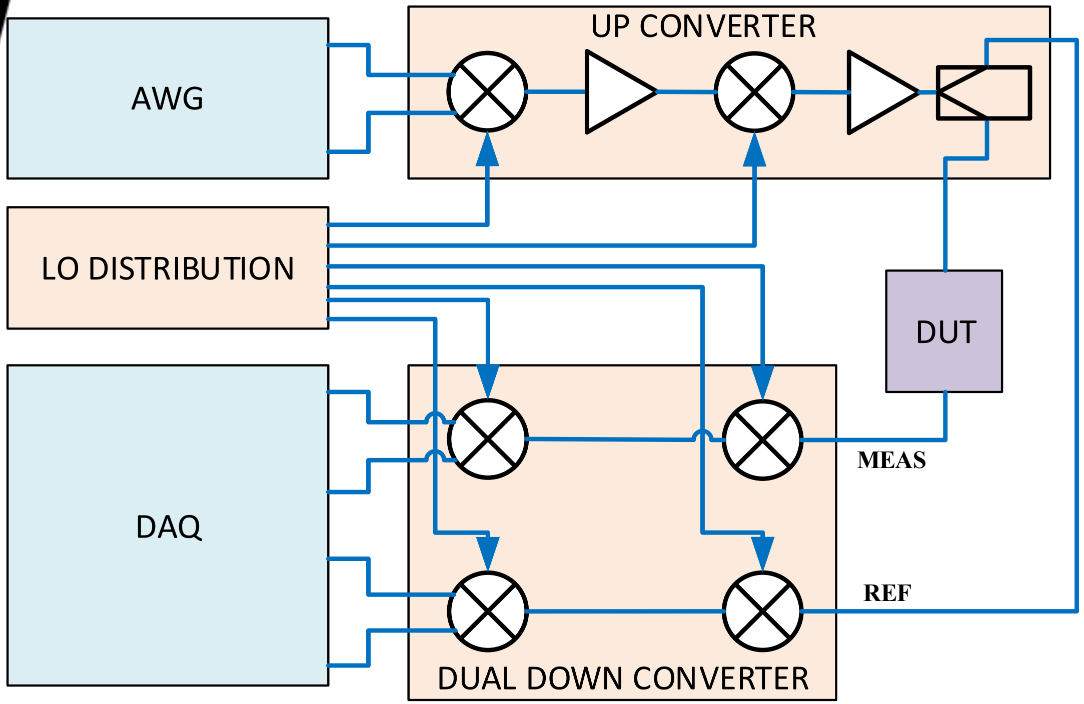
A 15km long temperature controlled FODL (fiber optic delay line) is used to characterize the radar interferometric performance. To make sure that the GSE (FODL in this case) does not dominate the phase and time-delay stability, FODL gets 1% of the overall radar error allocation. This leads to a 8ps common group delay requirement on a 15km optical fiber. For thermal vacuum measurements long waveguide runs (~3m) will be used to connect GSE to KaRIn. The differential phase stability requirement for KaRIn places constraints on the waveguide runs.

Simplified block diagram of PHEMUS



- Two main parts: 1) Digital PHEMUS and 2) RF PHEMUS
- Digital PHEMUS:
  - AWG (arbitrary waveform generator): Generates IQ pair based on Matlab code (10us PW, 105 MHz one sided BW, 8KHz PRF)
  - DAQ (Data Acquisition): Samples at 400MSamples/sec
  - RAIDs: 1min data~15GB. RAIDs used for high speed data collection.
- RF PHEMUS:
  - LO Distribution:
    - 10 MHz REF TXCO
    - 13.75 GHz
    - 22 GHz
  - Up Converter:
    - Dual-mixing approach
    - Converts from baseband to Ka-band
  - Dual down converter
    - REF path
    - MEAS path: includes DUT
    - Down conversion of both REF and MEAS signals to IQ pairs at baseband forming four IF signals.

Measurement Principle

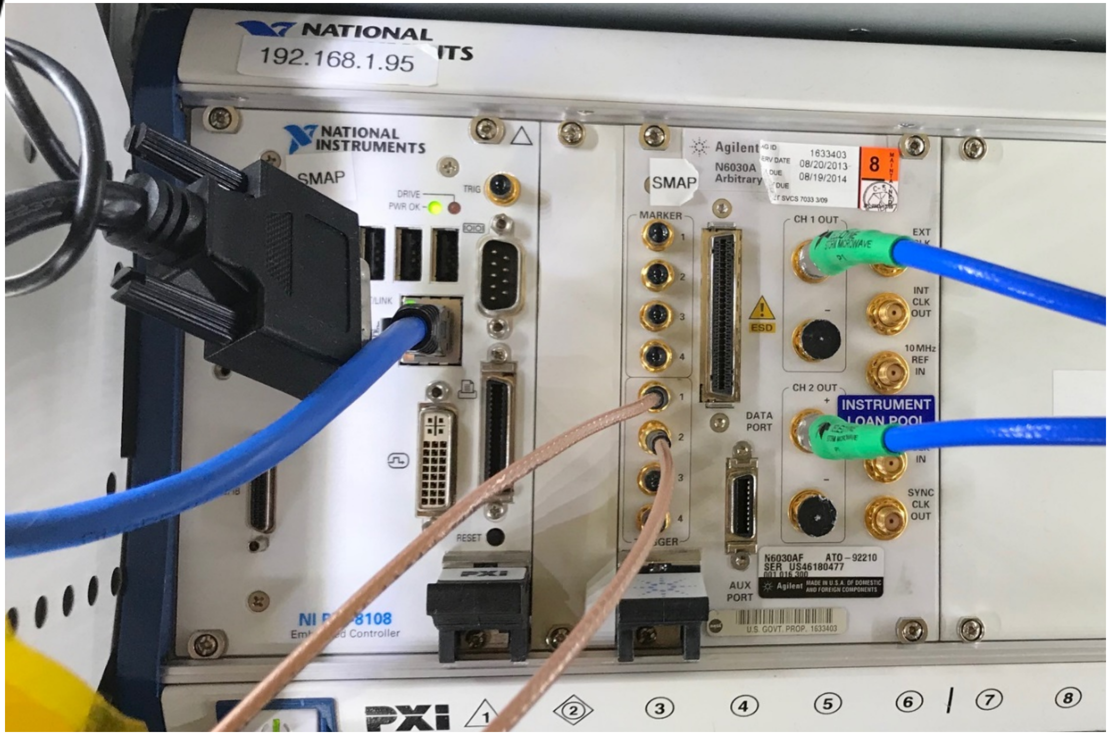


- Two down converter chains mounted next to each other undergo similar temp fluctuations and vibrations.
- When the two received signals are cross-correlated all the common mode signal is removed and the group delay of DUT is obtained using equation.

$$GD = \frac{d}{d\omega}\left(\arg\left(FFT(MEAS) * FFT(\overline{REF})^{*}\right)\right)$$

- For dual-channel DUTs, like parallel waveguides, information is sought on differential phase. In such cases, both MEAS and REF channels are used respectively for the two channels of the DUT.

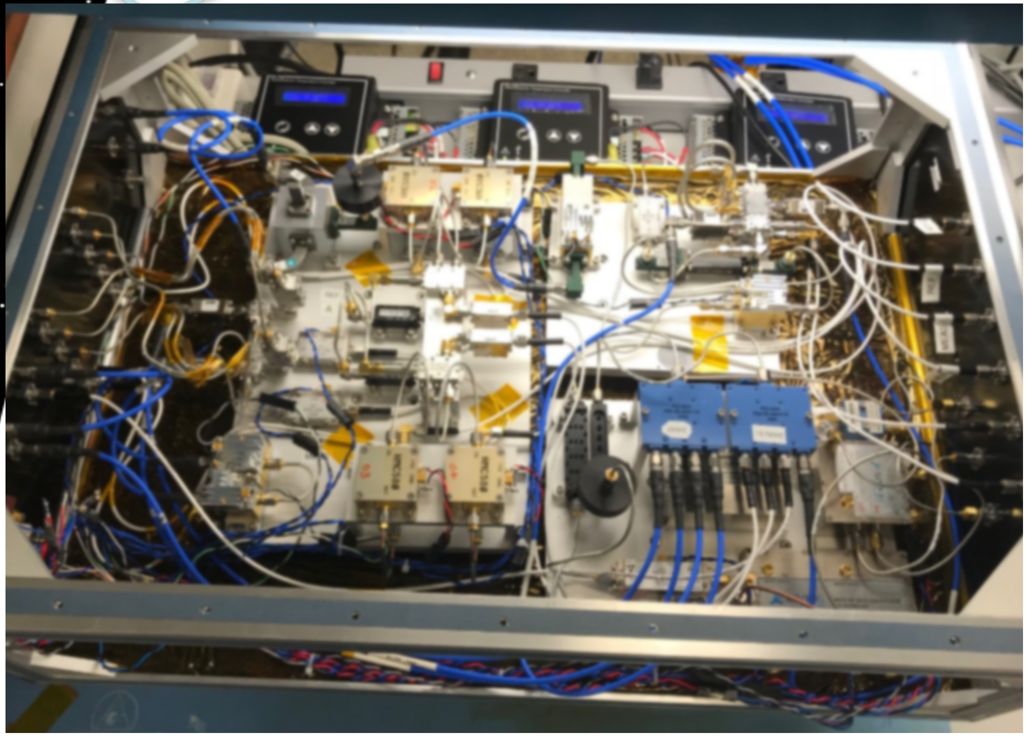
PHEMUS Digital Hardware



AWG

DAQ

PHEMUS RF Hardware

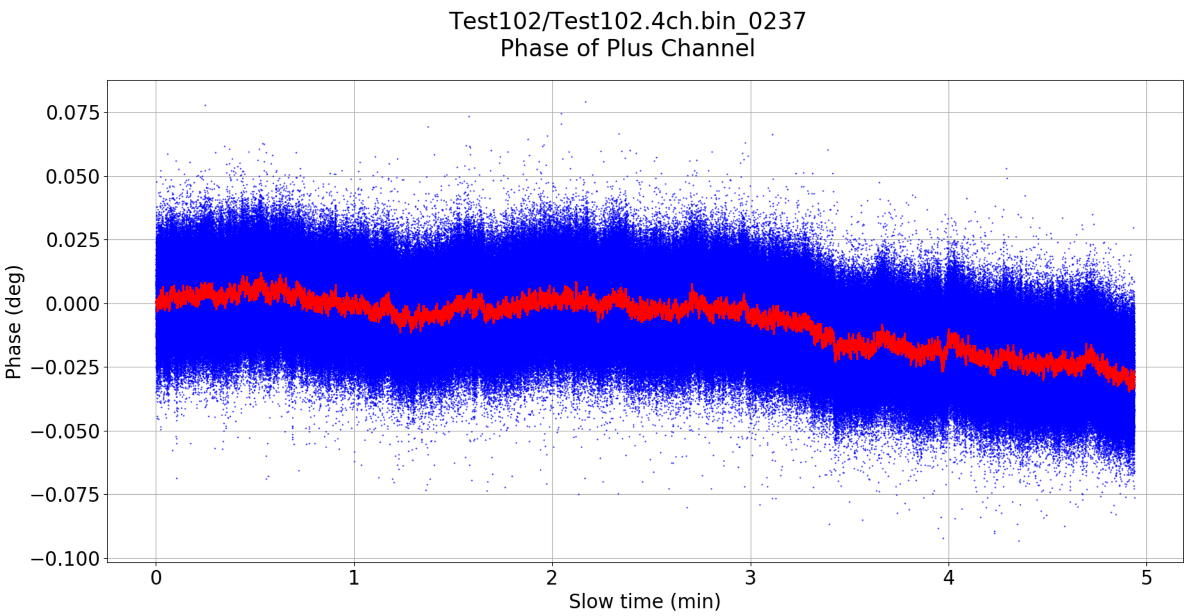


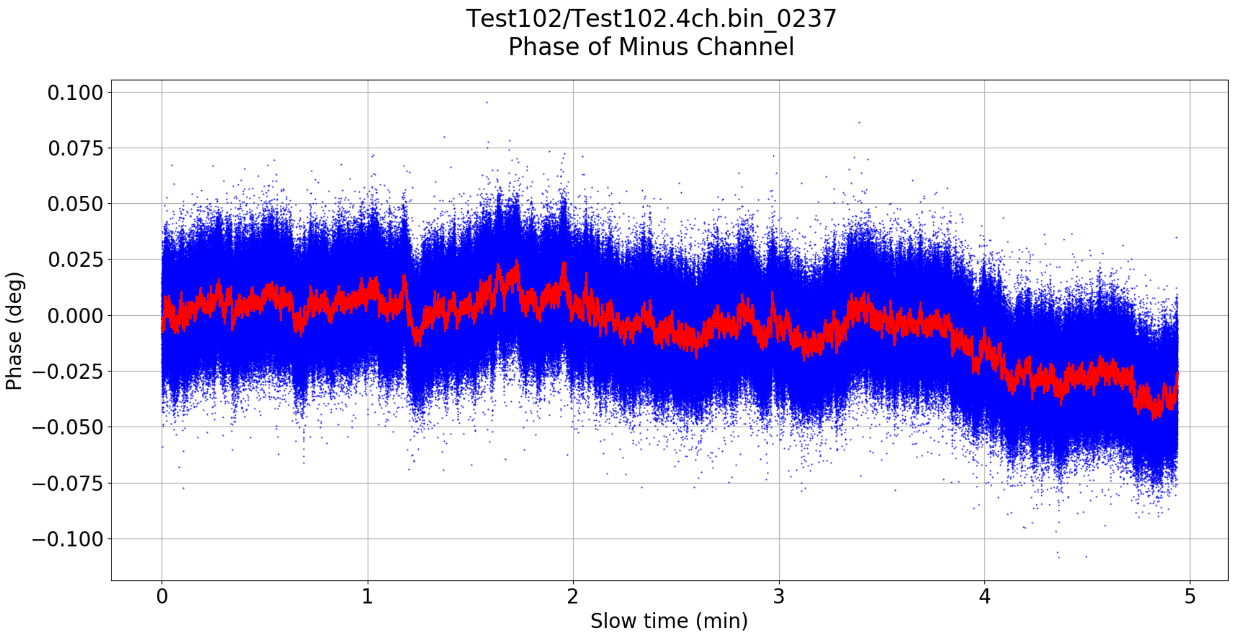
- Up converter:
  - Filters baseband AWG output to get rid of harmonics.
  - Amplification after first up conversion.
  - Driver amplifier and power amplifier after second up conversion.
- Dual down converter:
  - Two down converters mounted next to each other on a temperature controlled plate.
  - Phase matched cables and filters with similar group delays.
  - Modular design allows adding Ka and/or Ku amps depending on DUT.
- LO Distribution:
  - The LO sources are selected to have low phase noise.
  - The 13.75 GHz and 22 GHz LO sources generated inside the box and are locked to 10 MHz TXCO
  - Each LO is amplified, filtered and divided using four-way splitters.
  - Each LO is routed to its three corresponding mixer and the fourth to a test port on the front panel.

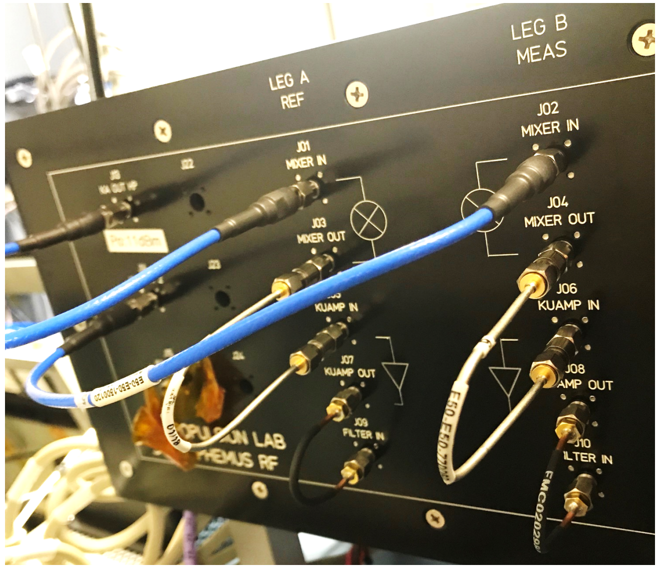
TEMPERATURE CONTROL

- 2.4^{0}C peak-to-peak change in ambient temperature caused by the laboratories HVAC system
- Three subsystems mounted on individual plates.
- Thick plates to increase thermal inertia.
- Thermoelectric coolers maintain plate at 25^{0}C.

PHEMUS BASELINE TEST RESULTS I

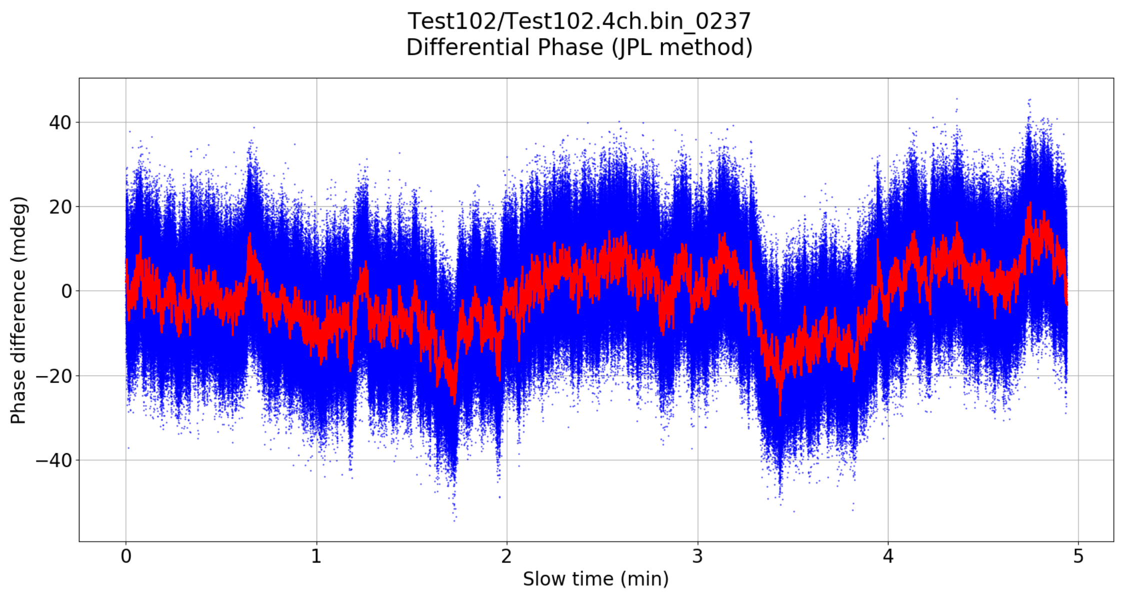




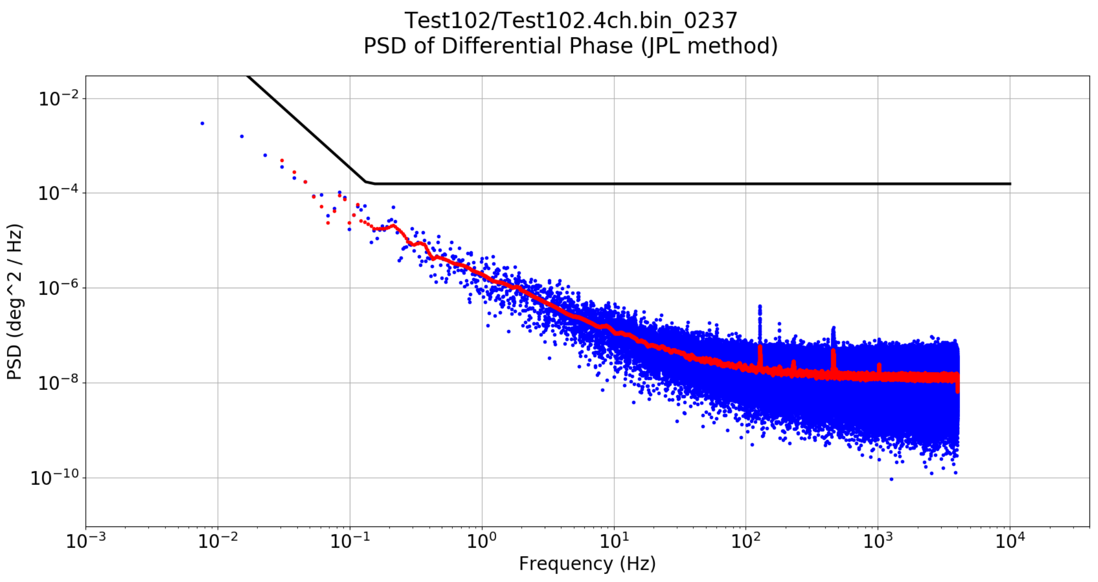


- Baseline configuration: NO DUT. REF and MEAS paths are equal.
- Plots show phase of REF and MEAS channels over a period of 5 minutes.
- Each point in the slow-time plot represents the average phase of a chirp.

PHEMUS BASELINE TEST RESULTS II

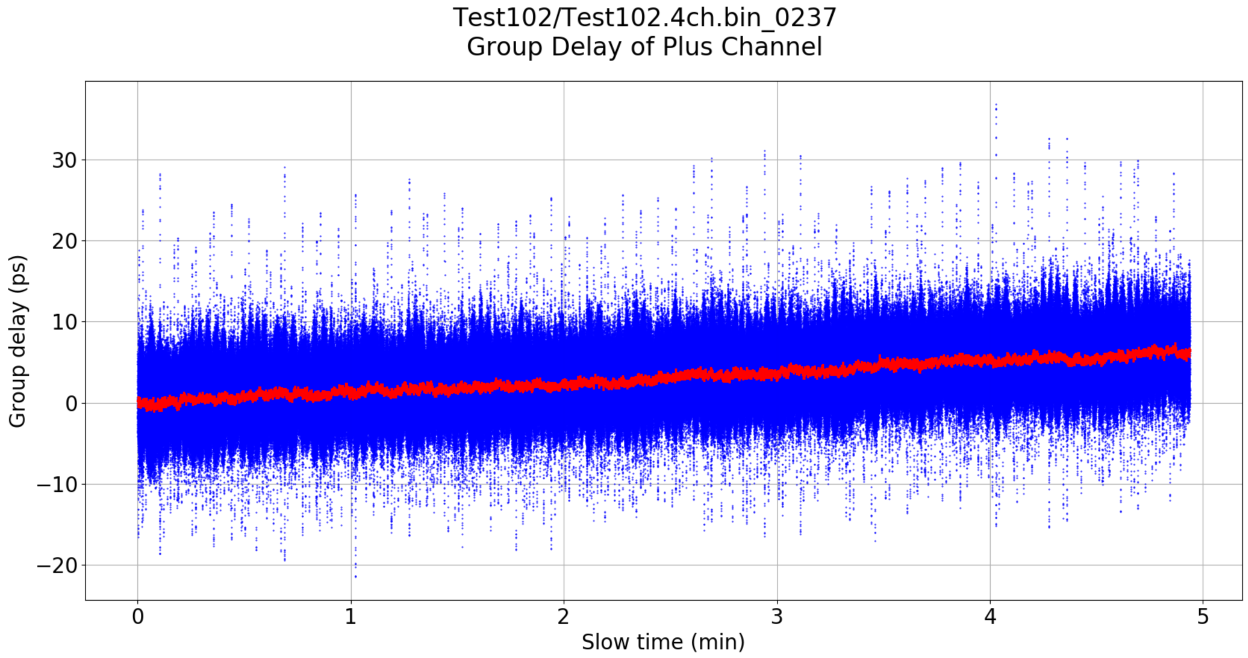


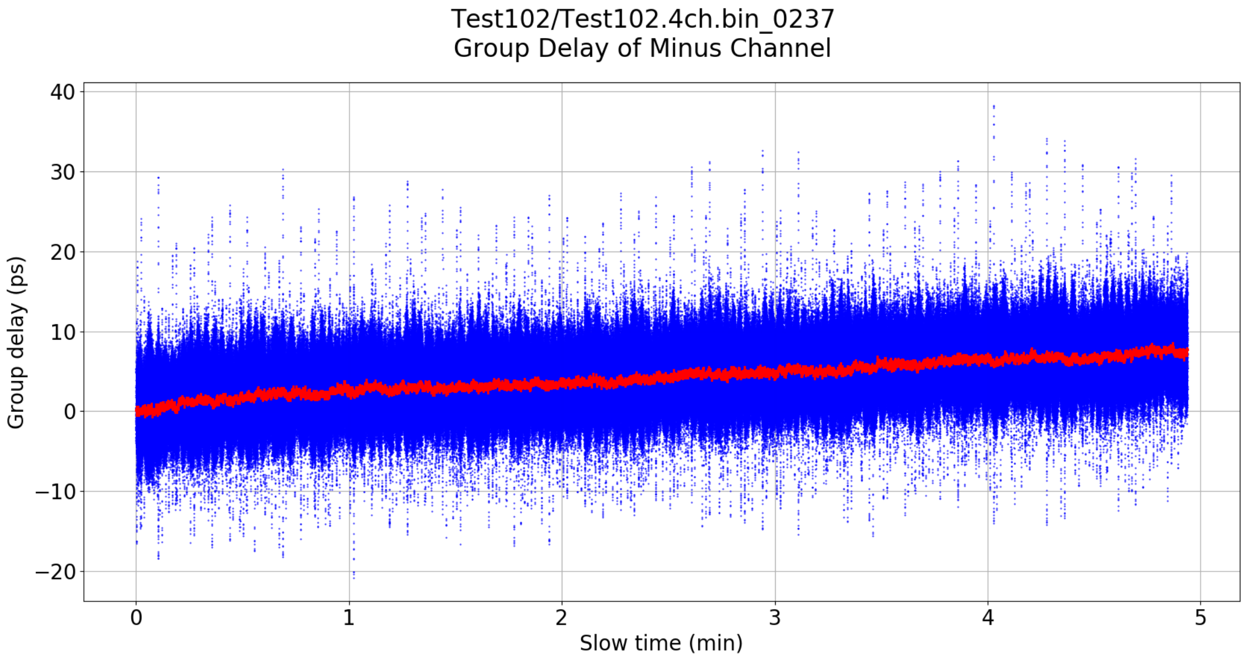
Differential phase



PSD of differential phase

PHEMUS BASELINE TEST RESULTS III



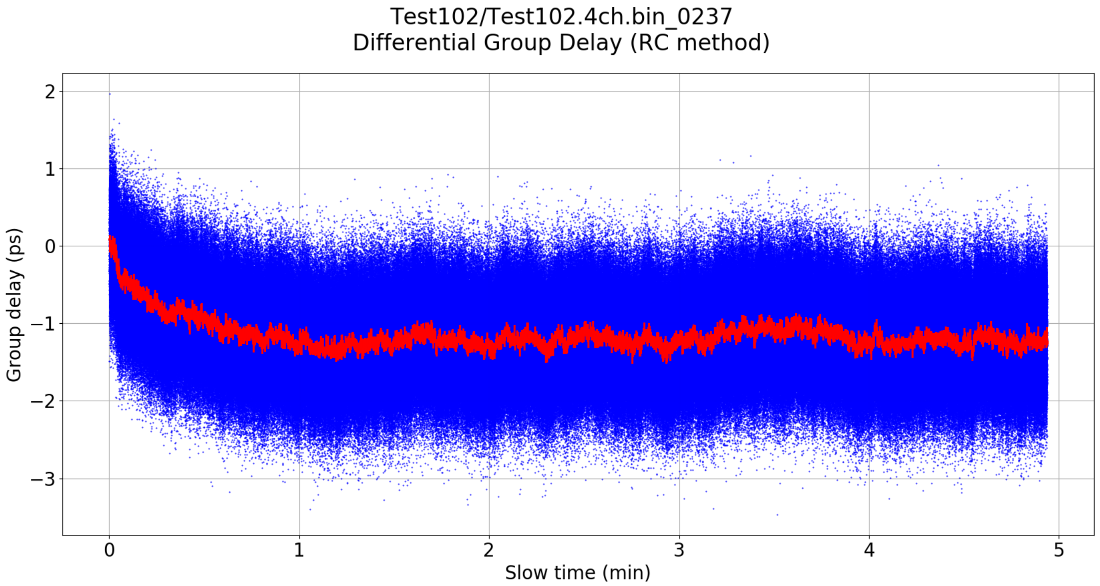


REF channel group delay

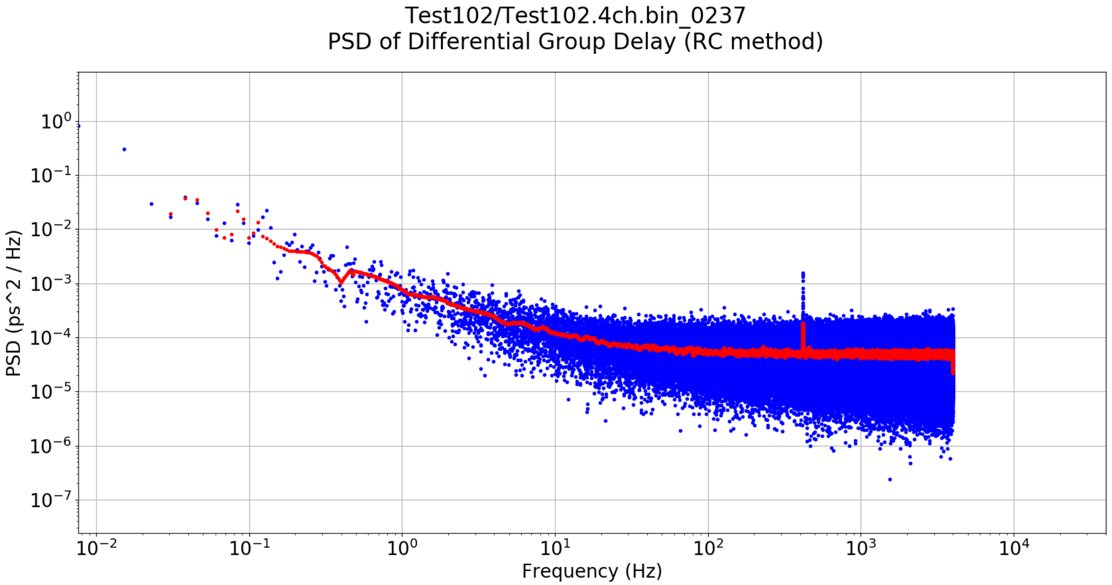
MEAS channel group delay

Each point in the slow-time plot represents the average group delay of a chirp.

PHEMUS BASELINE TEST RESULTS IV



Differential group delay



PSD of differential group delay

Summary

- SWOT mission will be NASA's first global survey of Earth's surface water
- To achieve centimeter-level accuracy, stringent requirements are imposed on radar performance in terms of differential phase and group delay.
- PHEMUS is developed for characterizing the GSE.
- Baseline results are presented.